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(1)  
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BRL

(14) BRL-460

(11) REPORT NO. 460

(13) APR 1944

(12) 23 p.

491944

(6) RETARDATION OF TUBULAR PROJECTILES DEVELOPED FROM  
THE 20MM AMERICAN BALL,

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(16) ORC-3858

Ordnance Research Center Project No. 3858  
BALLISTIC RESEARCH LABORATORIES



ABERDEEN PROVING GROUND, MARYLAND

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BRL - 460

RETARDATION OF TUBULAR PROJECTILES DEVELOPED FROM  
THE 20MM AMERICAN BALL

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Ballistic Research  
Laboratory Report No. 460

Ordnance Research Center  
Project No. 3858.

Charters/Thomas/bt/asf  
Aberdeen Proving Ground, Md.  
13 April 1944

RETARDATION OF TUBULAR PROJECTILES DEVELOPED FROM  
THE 20MM AMERICAN BALL

Abstract

Firings of 20mm projectiles with a tubular hole along the axis were conducted to measure the effect of such a hole on the retardation. The drag coefficient is found to decrease as the tube diameter increases. Comparison is made with the Standard 20mm ball projectile and a 20mm with a 30° conical windshield.

Introduction

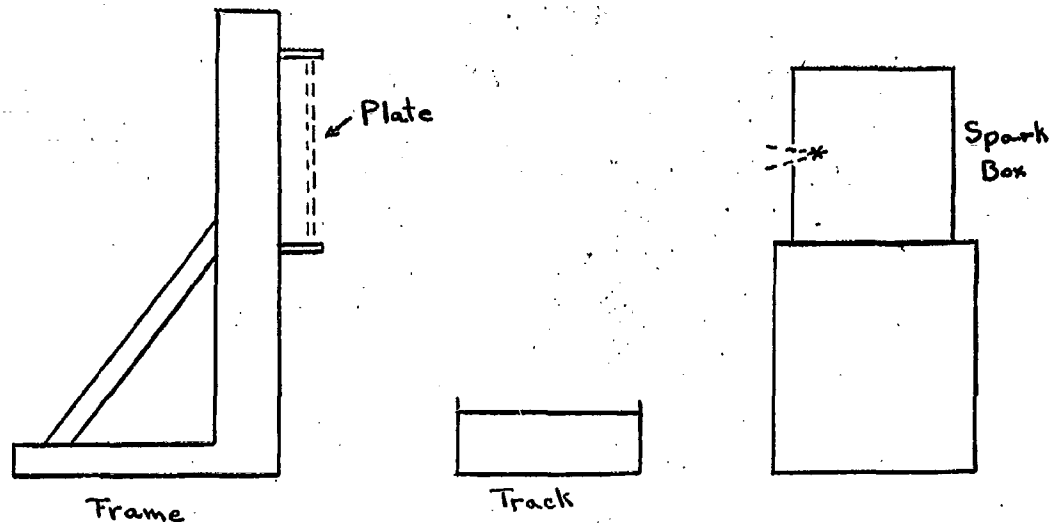
At various times the suggestion has been advanced that cutting a hole thru a projectile, along its axis, might materially increase its stability and decrease the retarding force of the air upon it. Therefore, at the request of the Ordnance Office, the present program was undertaken to measure the effect of such a hole upon the retardation. The program was unique in regard to experimental apparatus, for it was the first use of a group of spark photography units at Aberdeen for retardation measures. The apparatus was one of the later models for the spark photographic equipment now being used. (see ref. 1.)

A. Experimental

1. The experimental arrangement consisted of five spark photography stations. (see fig. 1.) These stations, as stated above, were models for the present apparatus, and consisted of an upright wooden frame, on which was mounted a photographic plate. This frame was placed to one side of the trajectory: directly across from it, mounted on another frame, was a box which housed the spark gap. A schematic diagram is shown below--the "track" is a concrete rail along which

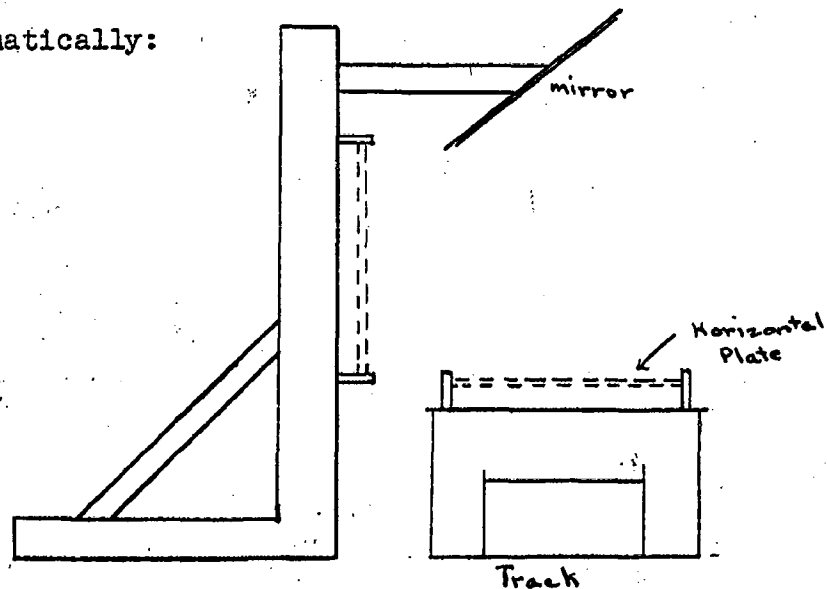


the gun is pointed.



This was the arrangement at stations 2, 3, 5. Since the spark box is a finite distance from the projectile, the image of the projectile on the photograph will be slightly displaced along the direction of motion from its true position. To correct for this, the distance of the projectile from the photographic plate must be known. Therefore at stations 1 and 4 a photographic plate in a horizontal plane was added. A mirror was placed above the frame, and tilted, so that the spark also illuminated this plate.

Schematically:



The projectile was assumed to travel in a straight line, so the projectile distance from the plate at stations 2, 3, 5 was interpolated. [From round No. 31-, a yaw card placed after station 5 was used in place of the horizontal plate at station No. 4; for round No. 30 hit and ruined the frame for this plate.]

At each station a plumb bob was suspended in front of the vertical plate; so that it was included in each photograph. The distances between plumb bobs were taped; so that measure of the photographs relative to the plumb bob enabled the total travel between successive photographs to be computed.

2. The signal from the spark gap, as it discharged, was relayed to the cathode ray oscillograph of the drum chronograph, and recorded on the chronograph film. Timing lines were superimposed on the film by feeding the output of a 10 kc frequency standard into a multivibrator, filtering and attenuating the signal, and thence sending it onto one plate of the oscillograph which recorded the signal on the film. Again, the timing circuit was an early model of that now in use. For a more complete description of this last, see References 1 and 5. The chief difference lies in the degree of uncertainty of the time of the spark signal. At times it was observed that the igniter spark caused the signal on the oscillograph, rather than the breakdown of the main spark gap. [In the present timing circuit, this defect has been remedied.] This caused an uncertainty in the time measures of some  $10^{-4}$  sec. The timing lines were spaced at  $100^{-4}$  sec; the speed of the drum was such that this corresponded to  $\sim 2$  mm. The films were measured with a comparator; so that the measuring accuracy was greater than that of the position of the spark signal. (see Note 1).

The basic data obtained thus consisted of spark photographs on 8 x 10 inch film at each of the five stations, and one chronograph record per round.

### 3. Accuracy of data

#### a. Distance

This falls into the two parts--measure of distance between plumb bobs and measure of the spark photographs.

The distance between plumb bobs was measured to an accuracy of  $\pm 0.005$  feet. The interval between stations was  $\sim 70$  feet.

The measuring accuracy on the photographs was  $\pm 0.05$  in. To translate this measure into the true position of the projectile, the "projection" factor  $1 - \frac{\text{distance projectile from plate}}{\text{distance spark}}$  must be known.

As stated previously, this was obtained by measuring position at stations 1 and 4, and assuming the projectile to move in a straight line between these. The accuracy of the relative position of the stations, i.e. their deviation from lying on a straight line, was  $\sim \pm 1/2$  inch. The "swerve" deviation of the projectile trajectory from a straight line would be, then, of order  $<$  the deviation of the positions of the stations. Since the projectile position was usually  $< 2$  inches from the plumb bob, and the spark box was  $\sim 48$  inches from the plate, the error introduced by the above  $\pm 1/2$  inch is  $\sim 2\%$  in the projection factor, or  $\lesssim 0.04$  inches. This gives an accuracy of  $\pm 0.010$  ft. in the distance measures.

#### b. Time

As stated before, the uncertainty in the time was  $\sim 10\mu$  sec.

#### c. Overall accuracy

From the preceding two factors, the accuracy in velocity, at  $v \sim 2800$  ft./sec., the velocity at which most of the rounds were fired, is  $\Delta v \sim 1$  ft./sec.

The retardations were 30-40 ft./sec./70 ft.; so an accuracy of  $\sim 5\%$  in  $K_D$  would be expected from a single retardation.

### B. Reduction of Data and Results

1. Five observations of time and distance were had from each round over a range interval of 280 feet. The most straightforward reduction would be to difference time and distance to give velocities, and velocities to give deceleration and drag coefficient. This would give three values of the latter from each round, an average giving a point on the drag curve.

It seemed more advisable to attempt some sort of smoothing of the initial data, times and distance, however; so the time was represented by a quadratic in the distance.

$$t = a + b(x - x_0) + c(x - x_0)^2$$

$x_0$  = coordinate of mid-range.

The five stations were constant in position so the times were corrected to put the projectile at the plumb bob, using the velocities obtained by straight differencing. Then the above equation was fitted by least squares--the right hand side being constant throughout--and one set of constants  $a, b, c$  found for each round.

The quantity of interest was  $K_D$ , defined by

$$\frac{d^2x}{dt^2} = \frac{\rho d^2}{m} \cdot K_D \cdot v^2$$

x = distance coordinate

t = time

$\rho$  = air density

m = projectile mass

d = " diameter

v = velocity

$K_D$  = drag coefficient - dimensionless and unitless.

Thus:  $v = 1/b$

$$\alpha = \frac{1}{v^2} \frac{d^2x}{dt^2} = \frac{1}{v} \frac{dv}{dx} = \frac{1}{b} \cdot 2c \quad \text{at } x = x_0$$

$$\text{and } K_D = \alpha \frac{m}{\rho d^2}$$

This procedure was done for each round; the result being a value of  $K_D$  and v at  $x_0$ .

## 2. Five types of projectiles were fired:

- a. Standard American ball
- b. " " " with a 30° conical windshield replacing the standard nose.
- c. Standard American Ball with a 1/4" hole cut along the axis.
- d. Standard American Ball with a the axis.

In the case of the projectiles with the hole cut through them, it was necessary to put in a base plug to seal the powder chamber. This plug was intended to come off when the projectile had left the muzzle and no longer had the powder pressure against its base. It was found that in some cases the plug of the larger holed projectile did not come out--so these were made the fifth group.

The results are given in tabular and graphical form. The notation used is:

B - Ball

W - windshield

S - Small hole projectile

L - Large hole projectile

LNP - Large hole projectile with plug

A photograph of the four types and a comparative outline is shown in fig. 2.

A table of the experimental results is given in fig. 3. The drag coefficient of each round is plotted on a graph against the Mach number in fig. 4. It should be noted that the Mach number scale is expanded to separate the individual values.

The velocities for all the rounds are very nearly the same, save for the type LNP. In any event, the velocity range for rounds of a given type is so small that it should not be construed as telling anything about the slope of the drag curve; but the points should be interpreted as defining a mean point, which is one value of  $K_D$ . The mean values of  $K_D$  are compared with the the drag coefficients for the M75, T9E4, and T9E5 projectiles in fig. 5 (see Ref. 5).

#### C. Comparison of Aerodynamic Performance

1. The diameter used in calculating the drag coefficient was taken to be 20mm for all types. It might be argued that the drag coefficient of the tubular projectiles should be based on an effective diameter computed from the projected area (ring shaped). However, the drag coefficient is in essence a similarity parameter and the one thing similar in projectiles fired from the same caliber gun is their outside diameter. Also, the drag force is directly proportional to the drag coefficient based on the caliber for projectiles traveling at the same velocity. For these reasons the full diameter was used.

The performance of a projectile from the standpoint of Exterior Ballistics depends on its muzzle velocity and its retardation. The muzzle velocity is a function of the shell's weight and the powder charge. The retardation is given by the equation:

$$\dot{V} = \frac{dV}{dt} = \frac{K_D \rho d^2 V^2}{m}$$

where

$\dot{V}$  = Retardation

$K_D$  = Drag coefficient

$\rho$  = Density of air

$d$  = Caliber of the projectile

$V$  = Instantaneous Velocity

$m$  = Mass of the Projectile.

If the powder charges of two shells having different weights are adjusted so that both are fired with the same muzzle velocity, a comparison of their retardations is given by the equation:

$$\frac{\dot{V}_1}{\dot{V}_2} = \frac{K_{D1}}{K_{D2}} \cdot \frac{m_2}{m_1}$$

Or if the powder charge is not changed the muzzle energy will stay constant approximately, that is

$$mV^2 = \beta = \text{constant}$$

So

$$\dot{V} = \frac{K_D \rho d^2 \beta}{m^2}$$

and

$$\frac{\dot{V}_1}{\dot{V}_2} = \frac{K_{D1}}{K_{D2}} \cdot \left(\frac{m_2}{m_1}\right)^2$$

It is equally plausible to assume launching conditions of either equal muzzle velocity and equal muzzle energy. For these two specific cases, a comparison of their retardations will depend only on the masses and drag coefficients. In the general case, the muzzle velocity will be determined by interior ballistic conditions. The weight will depend on both the shape and type of construction. The drag coefficient will be a function of the shape and velocity (Mach number).

It is the purpose of this report to compare the drag coefficients of tubular and solid shells of equal caliber. If the drag coefficient is established the exterior ballistic picture of any shell is readily completed once the design and launching conditions are fixed.

2. The designs of the tubular projectiles were developed logically from the standard 20mm American Ball. The American Ball has a méplat with a diameter just greater than 1/4". The first tubular projectile was made by drilling an axial hole the size of the méplat (1/4"). This tubular shell should be comparable in performance to the standard Ball since their shapes are identical except for the hole in one and the méplat on the other. The second tubular was made by drilling as large a hole thru the projectile as was consistent with interior ballistic requirements (15/32"). This tubular is similar to the 1894 Hebler projectile. The 1894 experiments are discussed in Note 2.

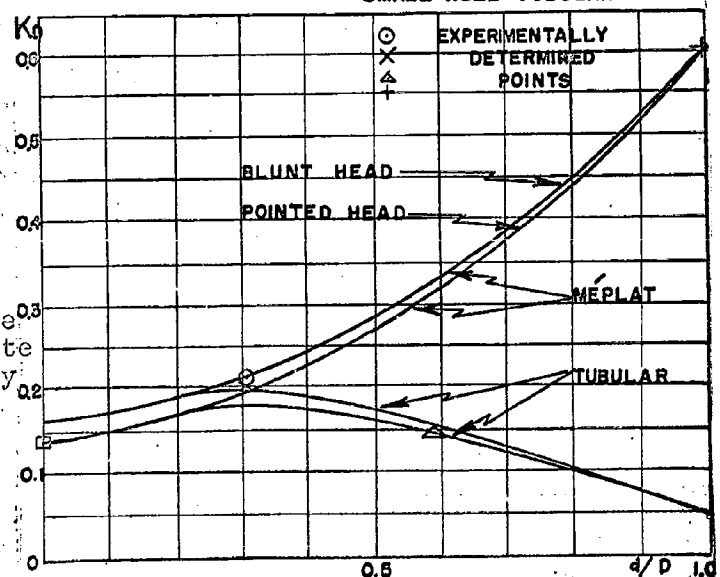
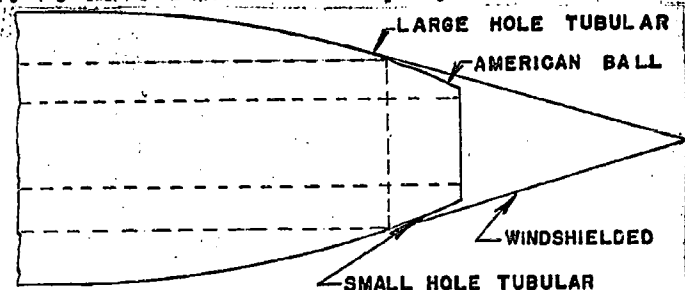
Also, since the 15/32" hole removes most of the original ogival head, its performance should be comparable to the 30° conical projectile. The 30° conical represents a well streamlined head shape whereas the American Ball has a poor aerodynamic form.

The most striking result is the comparison of the American Ball and the small hole tubular. Both have essentially the same drag coefficient (within 2%). In other words, drilling an axial hole thru the projectile the same size as its meplat did not reduce materially the drag coefficient.

Increasing the hole to double approximately the diameter decreased the drag 29% (based on the American Ball). The head shape of the Ball projectile is not well streamlined, however, and the windshielded shell was constructed in order to compare the tubular shells with a solid shell of really good aerodynamic design. The drag of the windshielded shell is lowest of all, being 31% less than the American Ball and 3% less than the Large Hole Tubular.

3. Tubular projectiles can be compared with solid shell more clearly perhaps if one refers to the accompanying sketch.\* Let us suppose that we have selected two projectiles alike except for head shape.

One has a blunt head shape, having a high drag, and the other has a sharp pointed head, having a low drag. Both head contours are continued to a point at the tip. These are the basic shapes. Then let us make a series of similar modifications on each shell in the following manner: Take each of the basic shapes and create a series of projectiles by cutting larger and larger sections off the nose. Each shell of the series will have a successively larger meplat and back of the meplat the same basic shape. Take the same basic shapes and create another series of shells by drilling larger and larger axial holes. Each tubular projectile will have its counterpart in a meplat projectile. Thus four series of projectiles will be formed:



\*The junior author (R.N. Thomas) does not necessarily concur in the construction of this sketch, or in the discussion based on it. A few remarks contrasting tubular and ordinary projectiles, with basis: nose shape a cone, will appear in a subsequent report.

1. Blunt basic shape: meplat
2.     "       "       "     : tubular
3. Pointed basic shape : meplat
4.     "       "       "     : tubular

Let us now plot on a graph all the drag coefficients as functions of the ratio of meplat or hole diameter respectively to the caliber,  $d/D$ . Each of the four series will have a single curve. There are 5 points on the curves which have been determined by experiment. From those established points the remainder of the curves will have to be drawn from a general knowledge of shell performance. The curves are not intended to be quantitatively accurate, but it is believed that they are correct for qualitative comparison.

The  $K_D$  curves for the meplat shells will slope upwards from the initial  $K_D$ s for the solid projectiles and join at a high  $K_D$ , the drag coefficient for a proof slug. The  $K_D$  curves for the tubular shells will also start from the initial  $K_D$ s for the solid projectiles. For the tubular projectile based on a blunt shape it will stay close to the meplat curve up to some value of  $d/D$  where it will branch and decrease with increase in  $d/D$ . For the tubular projectile based on a pointed shape, the shape of the curve at low values of  $d/D$  is somewhat uncertain. It may increase somewhat with  $d/D$  or it may stay approximately constant. The results of the present firings show that at  $d/D = 0.60$  the  $K_D$  for the tubular is a little greater than the basic shape. Probably the drag of tubular shells based on a pointed shape will not change much from the drag of the original solid shell. Beyond  $d/D$  of 0.60 the  $K_D$  will probably decrease. In fact, if one considers the hypothetical case of a tubular projectile that is all hole ( $d/D = 1$ ), the  $K_D$ s of the tubular shells will decrease to the same final value, a very small value, the skin friction drag. Of course, there is a practical limit to the value of  $d/D$  for a tubular projectile. This limit is probably about 0.7, based on the wall thickness of a 37mm H.E. shell. The Large Hole Tubular has a  $d/D$  of 0.60 and hence represents close to the practical limit for the tubular type.

The shapes of the curves as drawn indicate that a comparison of tubular and solid shells will depend largely on the basic shape. If the basic shape is blunt and has a high drag, the tubular curve will branch early from the meplat curve and it will have lower drag than its counterpart meplat shell or even the basic shape at moderate values of  $d/D$ . However, if the basic shape is pointed and has a low drag, the tubular curve will stay flat over a long range of  $d/D$ . The tubular shell will have a



lower drag than its counter part meplat shell but will have the same or a slightly higher drag than the original basic shape.

4. The crux of this investigation can be summed up in the result that the Large Hole Tubular shell and the Windshielded American Ball shell have essentially the same drag. The Windshielded shell has a slightly lower drag by 3%.

It is believed that the tubular represents an extreme of its type. It is doubtful whether any further substantial improvement can be realized. There is the possibility of tapering the hole for moderate values of  $d/D$ . This is usually done with the expanding section to the rear (see the 1894 tests and ref. 5) and for reasons of setback, etc., the Large Hole Tubular could be tapered but little. Some reduction in  $K_D$  might be effected by sharpening the nose. Again this method of improvement is not promising at large values of  $d/D$ . The drag is composed of head wave resistance, skin friction, and base drag. As the size of the hole approaches the size of the shell the skin friction becomes the controlling component. The head shape of the Large Hole Tubular is already comparatively sharply pointed and it is doubtful whether any further sharpening would greatly reduce the drag. The base cannot be boattailed for reasons of setback as already discussed. The Large Hole Tubular represents about the ultimate for its class.

The windshielded projectile, on the other hand, is only moderately well streamlined. Its nose shape is representative of a class of projectile designs having conical-ogival heads and a  $30^\circ$  cone is by no means the sharpest cone in service use. The 4.7" AA M73 HE projectile with a M61 fuze has a cone angle of  $20.5^\circ$ . The 8" M103 HE projectile with the M51 Mod. 1 fuze has a cone angle of  $17.8^\circ$ . The reduction in drag resulting from sharpening the head cone can be estimated from the calculation of Taylor and Maccoll on the drag of a cone (see ref. 2). The differential  $K_D$  between  $20^\circ$  and  $30^\circ$  cones is 0.040 for  $2 < M < 3$ . Consequently the drag of a 20mm projectile having a  $20^\circ$  conical nose would be expected to be about  $0.143 - 0.040 = 0.103$ . This  $20^\circ$  conical projectile would have 30% less drag than the Large Hole Tubular.

5. The conclusion drawn from the forgoing can be stated: The aerodynamic performance of a tubular projectile can be equaled or bettered by a well streamlined, solid projectile. Aerodynamic performance in this case means specifically the resistance of the projectile to the air, the drag. However, other considerations such as stability are satisfactory for both types. In view of the ballistic equations developed at the beginning of this section, it can also be said that if the aerodynamic characteristics of the tubular can be equaled or bettered by the solid projectile that its exterior ballistic characteristics can also be equaled or bettered. Aside from the muzzle velocity fired by the interior ballistics the only other factor in the ballistic equation, the weight, can be controlled by the structural design, metal used, etc.

The tubular projectile may have other unique advantages but in the interval from the gun to the target their performance is no better than a solid shell of good clean design. This conclusion has recently been substantiated by some recent firings carried out at the laboratory (see ref. 5). Their interior ballistic and terminal ballistic performance is beyond the scope of this report.

#### ACKNOWLEDGEMENT

The authors wish to express their appreciation to the members of the aerodynamics section and in particular to W. F. Braun and E. Richards for their assistance in carrying out the experimental program. Thanks are also due to Mr. Kent for suggesting this problem.

*A. C. Charters*

A.C. Charters

*R. N. Thomas*

R.N. Thomas

## NOTES

### Note 1.

It has frequently been stated by the group using the spark photography apparatus at the BRL that this technique is free from any inherent time lag errors. The spark that takes the picture also generates the chronograph signal. The assertion of no time lag is true for the modern spark apparatus in use at the present time. High speed oscillograph records show that the time between the spark and the chronograph signal is less than one microsecond.

At the time of the tubular projectile firings, a preliminary spark apparatus, now obsolete, was being used. This employed a needle point gap. The timing signal was taken directly from the spark capacitor discharge by a capacitive voltage divider and should have been sharp and clean. Unfortunately a mysterious "fuzz" appeared at the front or just slightly ahead of the main signal and so obscured its shape that we were unable to get the microsecond accuracy hoped for.

The laboratory did not have the proper equipment for the investigation of spark surges so arrangements were made thru Dr. A. W. Hull to carry out research at the General Electric Co. Laboratories at Schenectady under Dr. Lewi Tonks. One of the authors and an assistant\* had the privilege of working a full month on this problem in Dr. Tonks' laboratory.

The results of the investigation showed that the needle point gap had an irregular delay of from 5 to 20  $\mu$  sec. between the firing of the main gap and the initiating spark from the spark coil in the thyatron discharge circuit. The signal circuit responded to both signals and hence the "fuzz". The needle point gap was abandoned and a new gap was developed similar to one constructed by Dr. Tonks. Tests proved that the "Tonks" gap worked successfully with the main spark firing within one microsecond of the triggering spark. All the spark apparatus was immediately redesigned and all signals from our modern equipment are both faithful in regards to less than 1  $\mu$  sec. delay and clean in that they are single, sharp, well-defined spikes. The authors are greatly indebted to Dr. Tonks for his assistance in this problem.

\* A.C. Charters and W. F. Braun.

Note 2.

The tubular projectile is by no means a recent invention. So far as the authors know, its roots go back to 1893 to a tubular projectile called the Krnka-Hebler tubular projectile reported in the Allgemeine Schweizerische Militärzeitung. The performance of the Hebler bullet was described in so glowing and superlative terms in this journal that the Ordnance Department carried out firings of similar cal. .30 projectiles in 1894. (see ref. 3).

The techniques of Ballistic Measurements were quite different in 1894 than they are now. The concept of drag coefficient was rather obscure and the performance of shells was evaluated in terms of their trajectories as a whole. It is possible, however, by making a few simple assumptions to compute a drag coefficient from the 1894 Ballistic data and thus compare the 1894 results with the present firings. This has been done and the results agree remarkably well despite the lapse of 40 years.

Pfc. I. E. Segal has prepared at the suggestion of the author a brief description of the 1894 experiments and has reduced the results to modern form. His summary is in the form of a memorandum but since it is of excellent clarity and succinctness, it has been included without change. The authors are indebted to Pfc. I.E. Segal for the preparation of the excellent summary.

Interoffice Memorandum.

"

29 November 1943.

From: I. E. Segal

To: A. C. Charters

Subject: 1894 Experiment on Tubular Projectiles

1. Scope. The present memorandum describes the subject experiment and compares its results with those of the recent experiment on tubular projectiles conducted at the Ballistic Research Laboratory.

2. Description of experiment.

a. Each bullet was fired horizontally at a surveyed target approximately 1500 ft. from the gun.

b. The velocity of each bullet was measured at 53 ft. from the gun, probably by means of a Boulenge chronograph.

c. The vertical descent of each bullet over the 1500-foot range was measured on the target.

d. The average weight of each type of bullet was determined.

e. Altogether 122 bullets of six different types were fired, using vulcanized fiber sabots in the case of the tubular bullets.

### 3. Reduction of data and results.

a. Using the methods and tables of "Exterior Ballistics", by I. M. Ingalls, N.T., 1886, the ballistic coefficient and muzzle velocity are calculated for each condition of firing, from known elements of data consisting of the velocity at 53 feet and the vertical descent at 1490.766 ft. (see ref. 4).

b. The form factor (called "Coefficient of reduction" in the report) is also determined. (The standard projectile, on which the form factor is based, had an ogival head of 1.5 cal. radius and a cylindrical body, 215 calibers long, with a square cut bore). A modified form factor, defined by

$$i = \frac{m}{C (D^2 - d^2)}$$

is also computed for each tubular bullet, when D is the caliber and d is the average inner diameter.

c. In order to compare the 1894 results with the recent BRL experiments it is necessary to recompute the form factor based on the full diameter, D, rather than the effective diameter,  $d_e$ , where  $d_e = \sqrt{D^2 - d^2}$ . The ballistic coefficient computed by Ingalls' method from the experimental measures of muzzle velocity and drop depends very little on the value of  $i$  guessed initially for the purpose of data reduction. Consequently the C determined by the firings is almost independent of the value chosen for d. The form factor,  $i$ , is computed from the ballistic coefficient by the equation:

$$i = \frac{m/d^2}{C}$$

The form factor based on D can be computed from the original based on  $d_e$  by the equation:

$$i_D = i_{d_e} \times \frac{(D^2 - d^2)}{D^2}$$

d. There is an error in equation (1) on page 84 of the report of the experiment. The equation should read:

$$\frac{y}{x} = \tan \phi - \frac{C}{2 \cos \phi} \left\{ \frac{A(u) - A(v)}{S(u) - S(v)} - i(v) \right\}.$$

e. Various other quantities, such as energy of the shell at the target, etc., are computed.

f. It is not possible to compare accurately the 1894 experiment with the BRL experiment because the 1894 experiment determined the retardation of the shell over a long length of the trajectory. In order to reduce the drag coefficient from this type of data it is necessary to have prior knowledge of  $K_D$  as a function of Mach Number over the range of velocity covered. Ingalls assumed that the retardation was proportional to the square of the velocity for all velocities greater than 1300 ft./sec. He gives the equation for the drag (resistance) for the standard projectile as follows:

$$\text{Resistance} = 4.4137 \times 10^{-6} d^2 V^2$$

where

Resistance = Drag in pounds

d = Diameter in inches

V = Velocity in feet per second

(and the air density is 0.0758 lbs/cu.ft.)

Accordingly the  $K_D$  of the standard is 0.269 for

$$V \geq 1300 \text{ ft/sec. or } M \geq 1.15$$

The velocity range of the tubular projectiles was above 1300 ft/sec. for the 1500 ft. distance over which the vertical descent was measured, and falls in the region covered by the Ingalls formulae given above. The results of the 1894 experiment are given in terms of the ballistic coefficient and the form factor based on the standard projectile. If the drag coefficient of the tubular projectile is assumed constant or nearly so, then its drag coefficient is given by

$$K_D = i \times K_D \text{ standard.}$$

g. Two separate firing programs were carried out during the course of the 1894 experiment. The results are somewhat discrepant. In the first program the projection of the bore axis on the target was determined by visual sighting. In the second program the projection of the bore axis was determined by surveying methods using a level. On this basis alone the second shooting should be more accurate than the first. However, in the first program the most accurate group (5 shots) had an extreme variation in velocity at 53 ft. from the muzzle of 157 ft/sec. In the second program the muzzle velocity was measured for only one shot out of the best group (6 shots). The ordinates at the targets are 7.05 ft. and 6.7 ft. for the first and second program respectively. These results are discrepant by 4.9%. A variation in muzzle velocity of 157 ft/sec. would cause a variation in the ordinate of 10%. Only one shot of the second program group had its velocity measured and the variation in velocity over the remainder of the group could have caused a change in ordinate twice that observed between the two programs. For this reason only the results of the first program are reported in this memorandum.

h. The main results, reproduced from this report of the 1894 experiment, are these:

Type of Bullet*	Ballistic Coefficient	Form Factor based on Caliber.	$K_D$ **
1 (Service)	.30	1.10	.30
2	.22	1.10	.30
3 (Solid)	.24	1.03	.28
4	.21	1.19	.32
5	.29	.61	.16
6	.26	.54	.15

I. E. Segal

\* The number is the same as the corresponding figure number for Plate I in the report of this experiment.

\*\* According to Ingalls,  $K_D$  is constant for velocities greater than 1300 ft/sec. or Mach numbers greater than 1.15.

REFERENCES

1. BRL Report No. 425: Retardation of Fragments by W. F. Braun, A. C. Charters, and R. N. Thomas.
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3. Annual Report of the Chief of Ordnance to the Secretary of War for the Fiscal Year ended June 30, 1894, Appendices 6 and 7.
4. Exterior Ballistics in the Plane of Fire by James M. Ingalls.
5. BRL Report No. 457 : Aerodynamic Comparison of Gazda, M75, and T9E5 20mm Projectiles, by W. F. Braun, A. C. Charters, and R. N. Thomas.



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A2290 4-1-44

ABERDEEN PROVING GROUND

ORDNANCE DEPT.

Spark Photograph Apparatus.



AMERICAN BALL  
AB



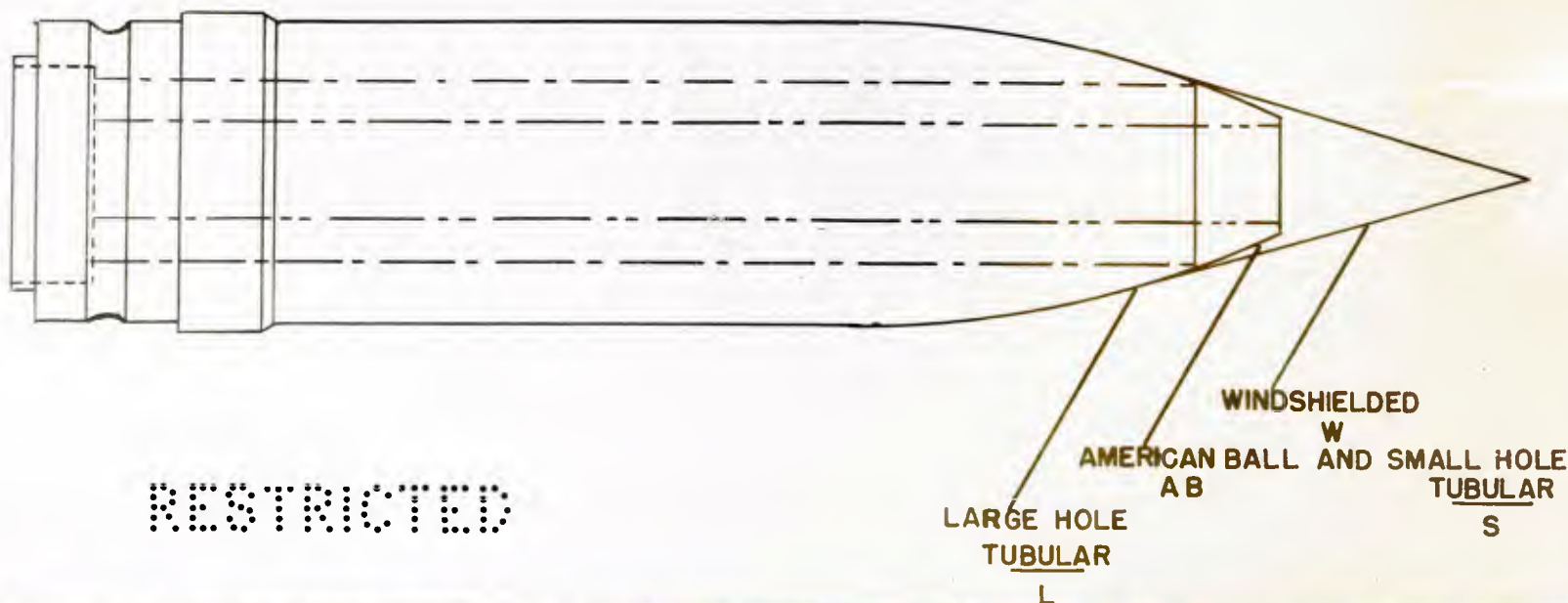
LARGE HOLE  
TUBULAR  
L



SMALL HOLE  
TUBULAR  
S



WINDSHIELDED  
W



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3-15-44

ABERDEEN PROVING GROUND

ORDNANCE DEPT.

20 mm Projectile, American Ball, Windshield Ball, 1/4" and 15/32" Tubular.

TABLE I  
EXPERIMENTAL RESULTS

RD.No.	Type	$\alpha$ 1/Ft.	$m/\rho d^2$ Ft.	V ft/sec.	M	$K_D$	M(ave)	$K_D$ (ave)
50B16	American Ball	$2.308 \times 10^{-4}$	871.0	2771	2.444	.201	2.416	.207
40B17		2.327	871.0	2753	2.428	.203		
33B8		2.369	873.0	2742	2.418	.207		
23B9		2.445	873.0	2726	2.404	.213		
28B7		2.408	876.0	2704	2.384	.211		
43L5	Large Hole	1.670	723.0	2749	2.424	.150	2.409	.147
39L9	15" tubular	2.082	720.0	2742	2.418	.149		
32L7	32 tubular	1.967	720.0	2704	2.384	.142		
60LNP13	Large Hole	4.475	720.0	2633	2.322	.323	2.300	.321
61LNP14	tubular	4.543	720.0	2632	2.321	.326		
37LNP8	plugged	4.393	720.0	2598	2.291	.317		
36LNP10		4.392	720.0	2568	2.265	.317		
52S3	Small hole 1/4" tubular	2.284	889.0	2795	2.465	.204	2.642	.202
45S10		2.278	889.0	2793	2.463	.203		
55S12		2.256	889.0	2786	2.457	.199		
17S6		2.222	889.0	2777	2.449	.198		
26S7		2.252	889.0	2774	2.446	.201		
19S2		2.295	889.0	2773	2.445	.204		
41S17		2.257	889.0	2771	2.444	.200		
31S5		2.289	889.0	2755	2.429	.206		
57W18	American Ball	1.700	846.0	2826	2.492	.144	2.450	.143
54W9		1.684	864.0	2784	2.455	.146		
29W8		1.639	860.0	2777	2.449	.141		
34W3-CR		1.605	864.0	2773	2.445	.139		
44W10		1.635	855.0	2770	2.443	.140		
35W6		1.669	848.0	2766	2.439	.142		
25W5		1.708	854.0	2756	2.430	.146		

\* d = 20mm for all rounds

Figure 3.



# DRAG COEFFICIENT

VS

## MACH NUMBER

$$K_D = \frac{M}{\rho d^2} \cdot \frac{1}{V} \cdot \frac{dY}{dX}$$

$M = \frac{\text{PROJECTILE VELOCITY}}{\text{SOUND VELOCITY}}$

SYMBOL	PROJECTILE 20MM
⊙	AMERICAN BALL
×	$\frac{1}{4}$ " SMALL HOLE TUBULAR
△	$\frac{15}{32}$ " LARGE HOLE TUBULAR
□	WINDSHIELD BALL
+	LARGE HOLE TUBULAR PLUGGED

$K_D$

0.3

0.2

0.1

2.2

2.3

2.4

2.5

M

FIG. 4

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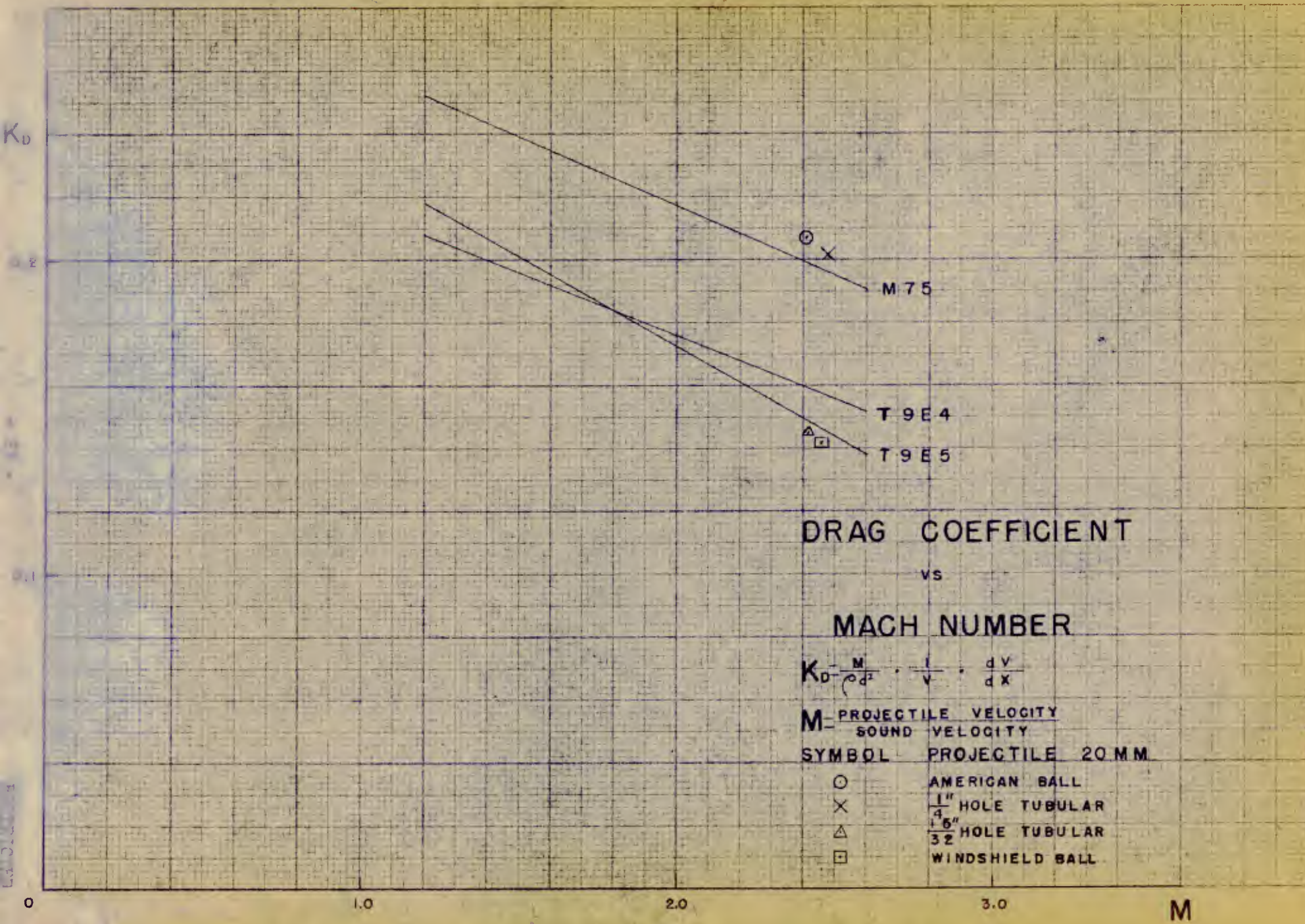


FIG. 5

REF. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100

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**TITLE:** Retardation of Tubular Projectiles Developed from the 20 mm American Ball

**AUTHOR(S):** Charters, A. C.; Thomas, R. N.  
**ORIGINATING AGENCY:** Aberdeen Proving Ground, Aberdeen, Md.  
**PUBLISHED BY:** (Same)

**ATI-** 4679

**REVISION** (None)

**ORIG. AGENCY NO.**  
BRL-460

**PUBLISHING AGENCY NO.**  
(Same)

DATE	DOC. CLASS.	COUNTRY	LANGUAGE	PAGES	ILLUSTRATIONS
April '44	Restr.	U.S.	Eng.	23	photos, tables, diagrs, graphs

**ABSTRACT:**

Firings of 20 mm projectiles with tubular hole along axis were conducted to measure effect of hole on projectile's stability and drag. A group of spark photography units were used for measurements to ensure freedom from time lag. Comparison was made with standard 20 mm ball projectile and a 20 mm projectile with 30° conical wind shield. Drag coefficient decreases as tube diameter increases. Drag coefficients versus Mach numbers were plotted on graph.

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**SUBJECT HEADINGS:** Projectiles - Aerodynamics (75415);  
Projectiles - Exterior ballistics (75415.8); Projectiles (75415.6); Projectiles - Stability (75419)

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